

Simulation—Writing Equilibrium Expressions

This simulation allows you to select a reaction type and the initial reactant concentrations, which the program uses to plot the resulting equilibrium graph. You will then be guided through a series of questions.

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Section 15.1 Questions

- Write a balanced equation with integer coefficients and the expression of the equilibrium law for each of the following reaction systems at fixed temperature.
 - Hydrogen gas reacts with chlorine gas to produce hydrogen chloride gas in the industrial process that eventually produces hydrochloric acid.
 - In the Haber process (Chapter 8), nitrogen reacts with hydrogen to produce ammonia gas.
 - At some time in the future, industry and consumers may make more extensive use of the combustion of hydrogen as an energy source.
 - When aqueous ammonia is added to an aqueous nickel(II) ion solution, the $\text{Ni}(\text{NH}_3)_6^{2+}(\text{aq})$ complex ion is formed (Figure 11).

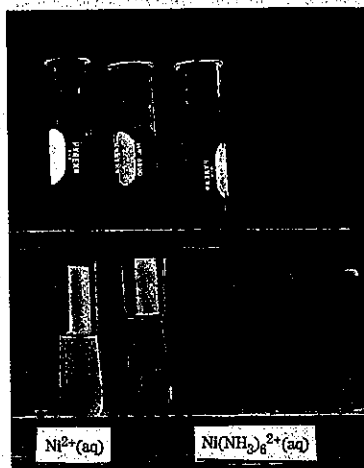


Figure 11
A $\text{Ni}^{2+}(\text{aq})$ solution is green. Ammonia reacts with the nickel(II) ion to form the intensely blue hexaammine-nickel(II) ion, $\text{Ni}(\text{NH}_3)_6^{2+}(\text{aq})$.

- In the Solvay process for making washing soda (Chapter 7), one reaction involves heating solid calcium carbonate (limestone) to produce solid calcium oxide (quicklime) and carbon dioxide.
 - In Investigation 15.1, aqueous solutions of sodium sulfate and calcium chloride are mixed. (Remember to use a net ionic equation.)
 - In a sealed can of soda, carbonic acid, $\text{H}_2\text{CO}_3(\text{aq})$, decomposes to liquid water and carbon dioxide gas.
- You can apply the empirical and theoretical concepts of equilibrium to many different chemical reaction systems. Use the generalizations from your study of organic chemistry to predict the position of equilibrium for bromine placed in a reaction container with ethylene at a high temperature.

- Interpret the graph in Figure 12 to answer the questions about the reaction. Hydrogen and iodine were placed in a reaction vessel, which was then sealed, and heated to 450°C .

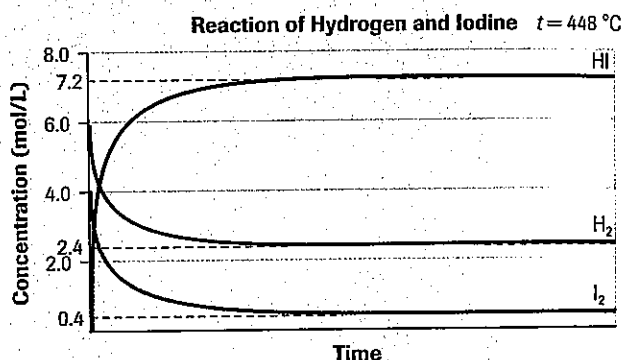


Figure 12

The progress of a hydrogen-iodine reaction

- All three substances are gases. If the container has a volume of 2.00 L, what chemical amount of each substance was present initially?
 - What chemical amount of hydrogen iodide had formed at equilibrium? (Create an ICE table.)
 - Describe the rate at which hydrogen is reacting from the moment the reactants are mixed to the time when equilibrium has been established, in terms of collision-reaction theory.
- For each of the following, write the chemical reaction equation with appropriate equilibrium arrow, as shown in Table 3 (page 680).
 - The Haber process is used to manufacture ammonia fertilizer from hydrogen and nitrogen gases. Under less-than-desirable conditions, only an 11% yield of ammonia is obtained at equilibrium.
 - A mixture of carbon monoxide and hydrogen, known as water gas, is used as a supplementary fuel in many large industries. At high temperatures, the reaction of coke and steam forms an equilibrium mixture in which the products (carbon monoxide and hydrogen gases) are favoured. (Assume that coke is pure carbon.)
 - Because of the cost of silver, many high school science departments recover silver metal from waste solutions containing silver compounds or silver ions. A quantitative reaction of waste silver ion solutions with

copper metal results in the production of silver metal and copper(II) ions.

(d) One step in the industrial process used to manufacture sulfuric acid is the production of sulfur trioxide from sulfur dioxide and oxygen gases. Under certain conditions, the reaction produces a 65% yield of products.

5. Write the expression of the equilibrium law for the hydrogen-iodine-hydrogen iodide system at 448 °C. Using the evidence for System 1 as reported in Table 1 on page 679, calculate the value of the equilibrium constant.

6. In the Haber process for synthesizing ammonia gas from nitrogen and hydrogen, the value of K_c is 6.0×10^{-2} for the reaction at 500 °C. In a sealed container at equilibrium at 500 °C, the concentrations of $H_2(g)$ and of $N_2(g)$ are measured to be 0.50 mol/L and 1.50 mol/L, respectively. Write the equilibrium law expression and calculate the equilibrium concentration of $NH_3(g)$.

7. At a certain constant (very high) temperature, 1.00 mol of $HBr(g)$ is introduced into a 2.00 L container. Decomposition of this gas to hydrogen and bromine gases quickly establishes an equilibrium, at which point the amount concentration of $HBr(g)$ is measured to be 0.100 mol/L.

(a) Write a balanced equation for the reaction.

(b) Write the equilibrium law expression.

(c) Calculate the chemical amount of $HBr(g)$ present at equilibrium.

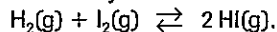
(d) Calculate the chemical amount of $HBr(g)$ that has reacted to form $H_2(g)$ and $Br_2(g)$ products when equilibrium is established.

(e) Calculate the chemical amounts of $H_2(g)$ and $Br_2(g)$ that have been produced, and, thus, are present, when equilibrium is established.

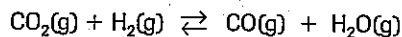
(f) Calculate the amount concentration of all substances present at equilibrium.

(g) Calculate K_c for this reaction at this temperature.

8. To a heated reaction vessel with a volume of 1.00 L, a lab technician adds 6.23 mmol $H_2(g)$, 4.14 mmol of $I_2(g)$, and 22.40 mmol of $HI(g)$. At equilibrium, a spectrophotometer is used to determine that the concentration of iodine vapour is 2.58 mmol/L. Construct an ICE table and find K_c for the reaction system

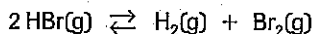


9. Consider the system



Initially, 0.25 mol of water and 0.20 mol of carbon monoxide are placed in a 1.0 L reaction vessel. At equilibrium, spectroscopic evidence shows that 0.10 mol of carbon dioxide is present. Construct an ICE table and find K_c for this system.

10. Consider the system



Initially, 0.25 mol of hydrogen and 0.25 mol of bromine are placed into a 500 mL electrically heated reaction vessel. K_c for the reaction at the temperature used is 0.020.

(a) Find the concentrations of the substances at equilibrium.

(b) Calculate the chemical amount of each substance present at equilibrium.

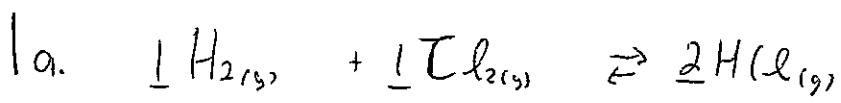
11. Explain briefly how atomic theory, kinetic molecular theory, collision-reaction theory, and the concepts of reaction rate and reversible reactions are all necessary to explain chemical reaction equilibrium observations.

Extension

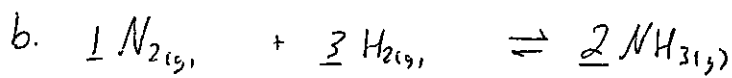
12. In a *very* long-term sense, Earth may be considered a closed system. One equilibrium of concern to scientists is the same one involved in carbonation of soft drinks, on a vastly larger scale. Scientists believe that over time, the carbon dioxide gas in the atmosphere should be in equilibrium with carbon dioxide dissolved in the oceans. They also know that the concentration of $CO_2(g)$ in the atmosphere has been increased significantly (by about 20%) in the last century, which, they believe, is mostly due to the burning of fossil fuels. Concerns about the consequences of global warming make it imperative that scientists improve their theories about the various cycles, processes, and equilibria involving this greenhouse gas. Research and summarize currently accepted theory about carbon dioxide dissolved in the oceans, and list some other cycles and systems involving reaction or production of $CO_2(g)$.

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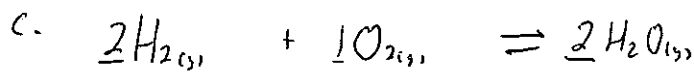




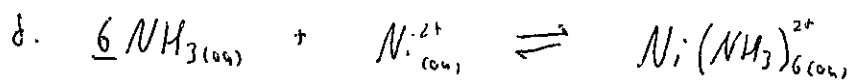
$$K_c = \frac{[HCl_{(g)}]^2}{[H_{2(g)}][Cl_{2(g)}]}$$



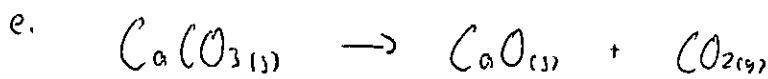
$$K_c = \frac{[NH_{3(g)}]^2}{[N_{2(g)}][H_2]^3}$$



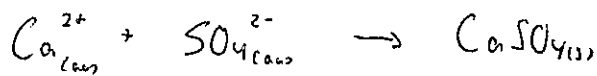
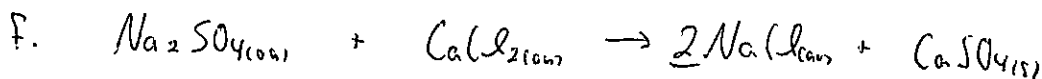
$$K_c = \frac{[H_2O_{(g)}]^2}{[H_{2(g)}]^2 [O_{2(g)}]}$$



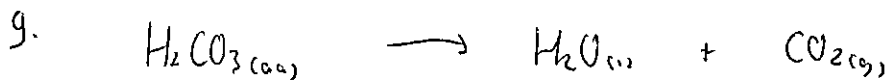
$$K_c = \frac{[Ni(NH_3)_6^{2+}]}{[NH_{3(aq)}]^6 [Ni^{2+}_{(aq)}]}$$



$$K_c = [CO_2]$$



$$K_c = \frac{1}{[Ca^{2+}_{(aq)}][SO_4^{2-}_{(aq)}]}$$



$$K_c = \frac{[CO_{2(g)}]}{[H_2CO_{3(aq)}]}$$

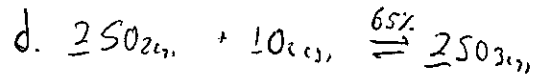
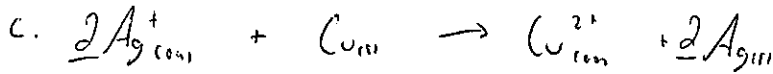
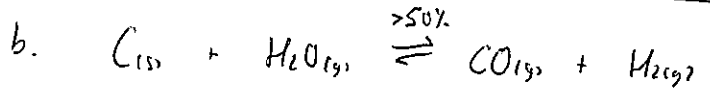
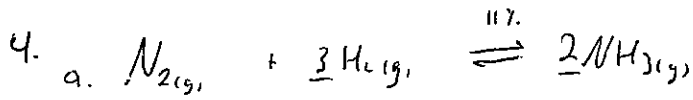
3a. $n_{HI} = CV$
 $= \frac{0.0}{\cancel{1.0} \text{ mol/l}} (2.00 \text{ L})$
 $= \frac{0.0}{\cancel{1.0} \text{ mol}} \text{ mol}$

$n_{H_2} = CV$
 $= \frac{6.0}{\cancel{1.0} \text{ mol/l}} (2.00 \text{ L})$
 $= \frac{12}{\cancel{1.0} \text{ mol}} \text{ mol}$

$n_{I_2} = CV$
 $= \frac{4.4}{\cancel{1.0} \text{ mol/l}} (2.00 \text{ L})$
 $= \frac{8}{\cancel{1.0} \text{ mol}} \text{ mol}$

b. $n_{HI} = CV$
 @ eq. $= (7.2 \text{ mol/L})(2.00 \text{ L})$
 $= 14.4 \text{ mol}$

c. H_2 is initially reacting quickly b/c there is lots of it present, but as it reacts there is less of it and the rate at which it reacts slows down b/c there are fewer collisions between $H_2 + I_2$ reacting



6. $3H_2(g) + N_2(g) \rightleftharpoons 2NH_3(g)$
 $k_c = \frac{[NH_3]^2}{[H_2]^3 [N_2]}$ $0.060 = \frac{[NH_3]^2}{(0.50)^3 (1.50)}$
 $[NH_3] = 0.11 \text{ mol/L}$

(g) $k_c = \frac{(0.200 \text{ mol/L})(0.200 \text{ mol/L})}{(0.100 \text{ mol/L})^2}$
 $= 4.00$

(b) $k_c = \frac{[Br_2][H_2]}{[HBr]^2}$

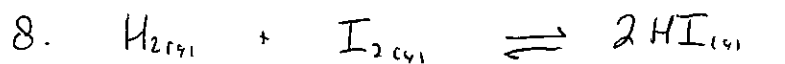
(c) $n = CV$
 $= (0.100 \text{ mol/L})(2.00 \text{ L})$
 $= 0.200 \text{ mol}$

(f) $C_{HBr} = \frac{0.200 \text{ mol}}{2 \text{ L}}$
 $= 0.100 \text{ mol/L}$

$C_{H_2} = \frac{0.400 \text{ mol}}{2.00 \text{ L}}$
 $= 0.200 \text{ mol/L}$ ← some for Br₂

7. $2HBr(g) \rightleftharpoons H_2(g) + Br_2(g)$

I	1.00 mol (d)	0	0
C	-0.800 mol (d)	+0.400 mol	+0.400 mol (e)
E	0.200 mol (d)	0.400 mol	0.400 mol



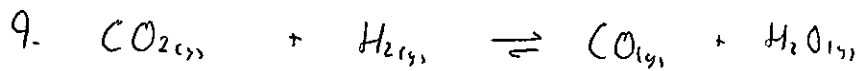
I	6.23 mol/L	4.14 mol/L	22.40 mol/L
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C	-1.56	-1.56	+ 3.12
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E	4.67	2.58 mol/L	25.52
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$$K_c = \frac{[\text{HI}]^2}{[\text{H}_2][\text{I}_2]} = 54.05 \dots$$

$$= \boxed{54.1}$$



I	0	0	0.20 mol/L	0.25 mol/L
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C	+ 0.10	+ 0.10	- 0.10	- 0.10
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E	0.10 mol/L	0.10	0.10	0.15
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$$K_c =$$